



Multi-Wavelength Laser Transmitter for the Two-Step Laser Time-of-Flight Mass Spectrometer

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Agenda



- Motivation
- L2MS Instrument Overview
- L2MS Laser Architecture
- Preliminary Performance
- Future Work & Conclusions



Agenda



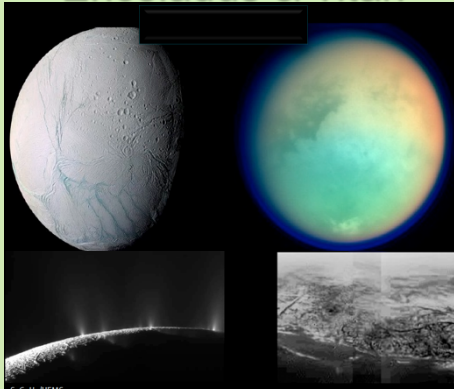
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Science Motivation



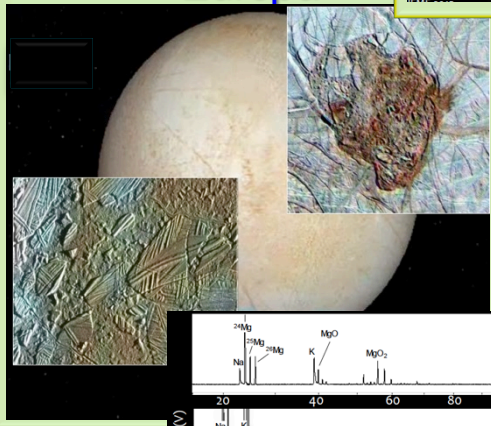
Enceladus & Titan



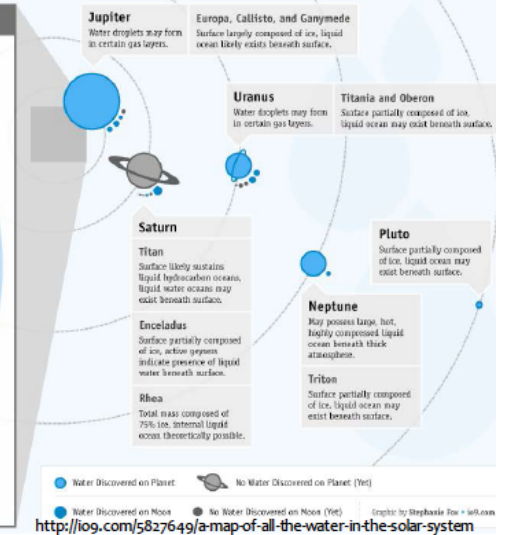
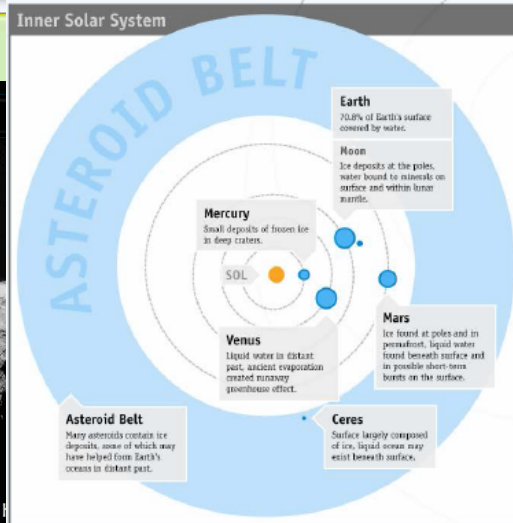
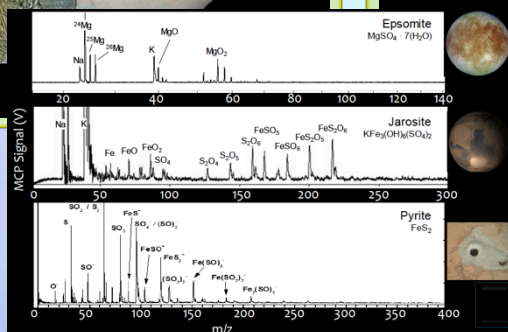
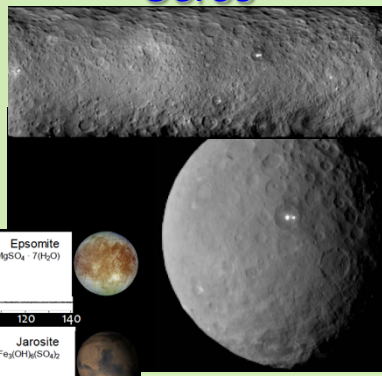
Comets



Europa



Ceres



All these bodies contain volatiles, including water just waiting to be analyzed

Our science motivation is to seek a solution with "Universal" detector for

- Comprehensive sample analysis
- Flexibility to adapt for different mission architectures including flybys, orbiters, landers, and/or rovers!



Agenda



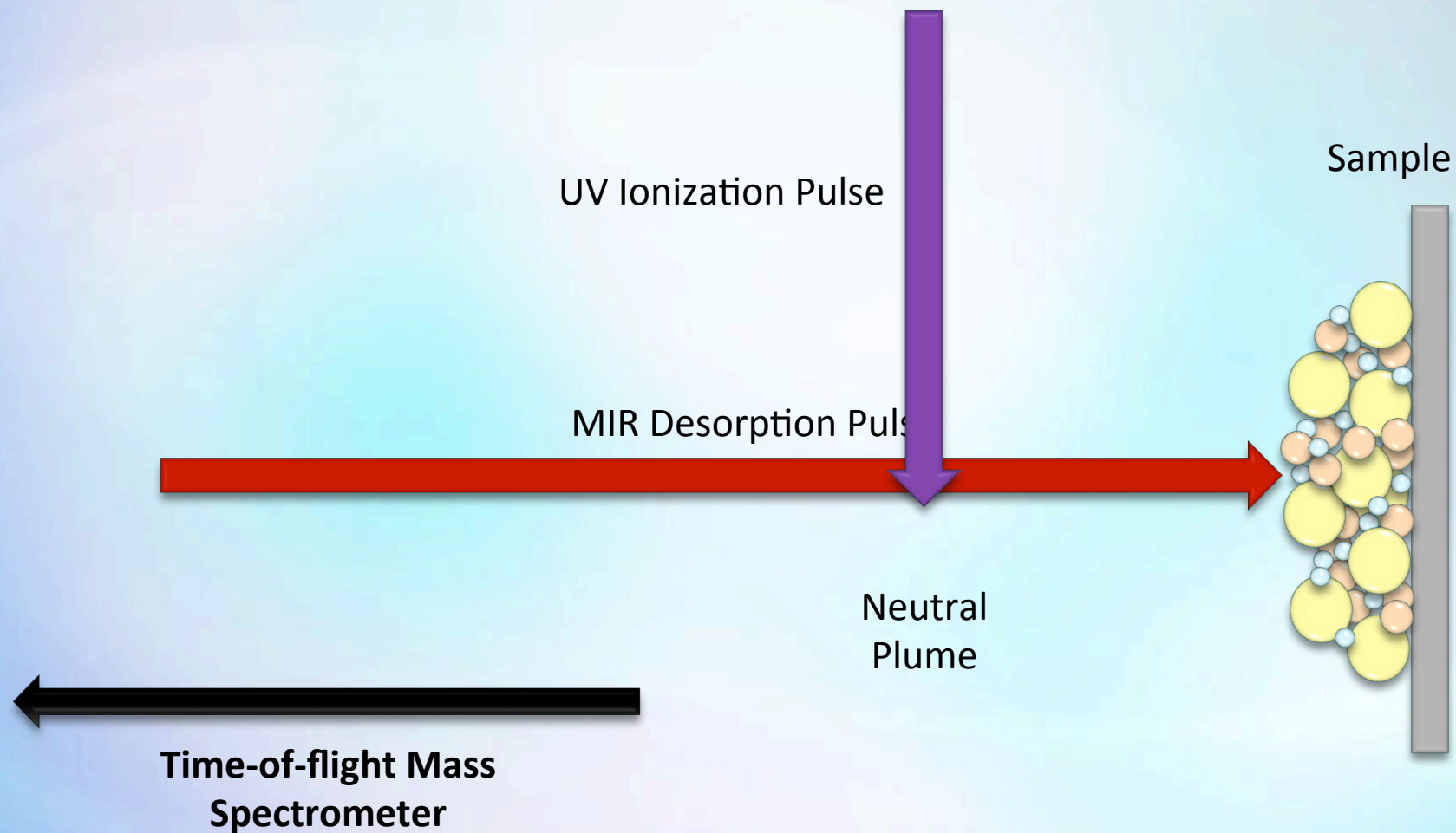
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L2MS Instrument Overview



Laser Desorption/Ionization Mass Spectrometry

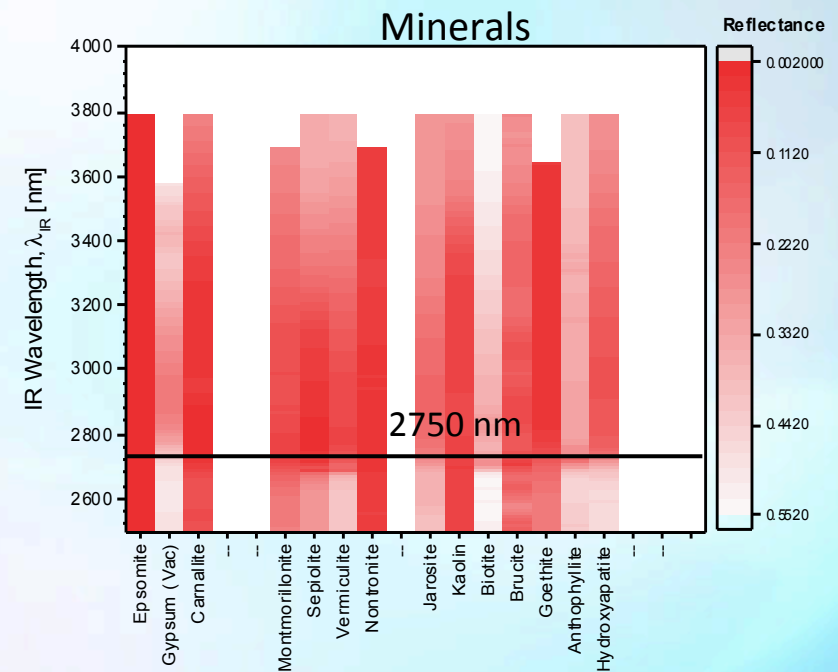
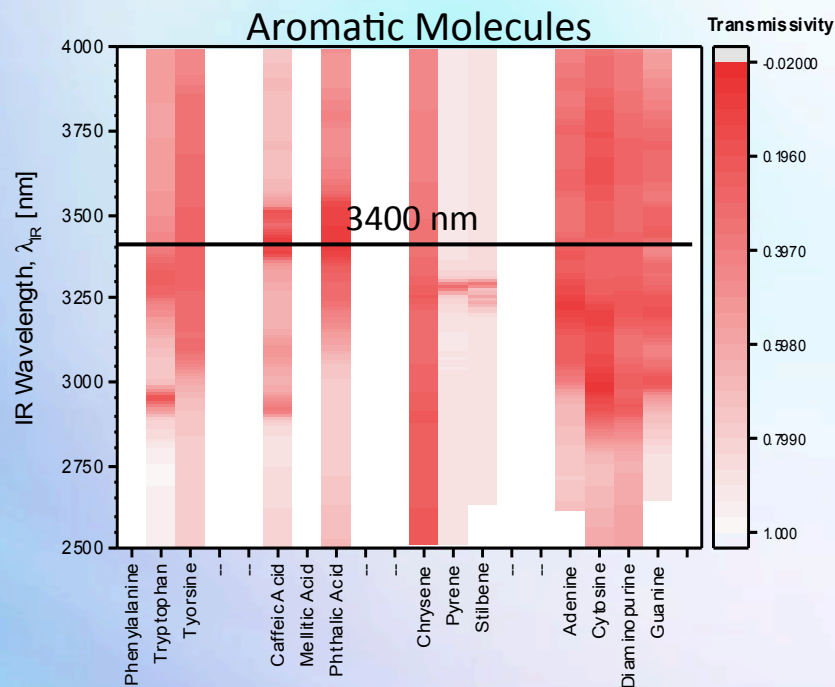




L2MS Instrument Overview

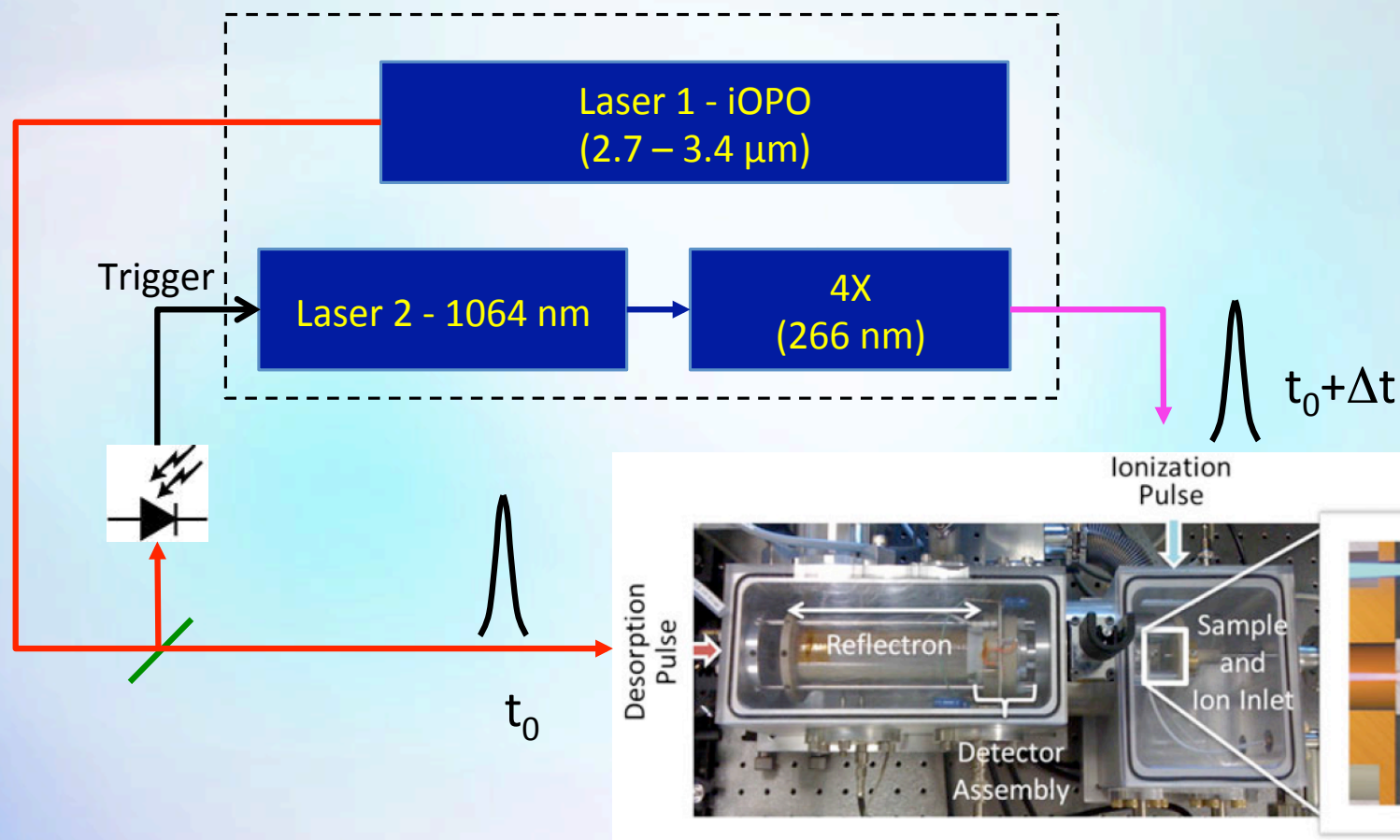


- Wavelengths are selected based on key vibrational and electronic resonances in the targeted species aligned with the organic diversity and mineralogy expected for future planetary missions of high priority to NASA
 - 2.75 μm - IR vibrational resonances of hydrated minerals
 - 3.4 μm - C-H vibration resonance of organic species
 - 266 nm - coincides with a short-lived metastable state in many aromatic molecules
- Matching MIR laser wavelength allows for selective desorption





L2MS Instrument Overview



- Typical delay between Laser 1 and Laser 2 (Δt) range between 0.3-2 μs



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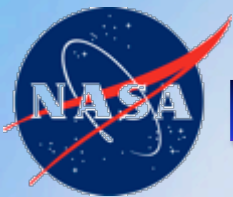
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L2MS Laser Requirements



Lasers Requirement	MIR Laser	UV Laser
Pulse Repetition Frequency (PRF)	1 – 20 Hz	1 – 20 Hz
Wavelength	2.8X μm and $3.40 \pm 0.05 \mu\text{m}$	266 nm
Energy	$\sim 100 \mu\text{J}$	$\sim 18 \mu\text{J}$
Pulse Width	$< 7 \text{ ns}$	$< 7 \text{ ns}$
Peak Power	$\sim 14 \text{ kW}$	$\sim 2.5 \text{ kW}$
Peak Intensity (assuming 100 μm beam diameter)	180 MW/cm^2	$\sim 30 \text{ MW/cm}^2$
Spectral Width	Few GHz	Few GHz
Timing	t_0	$t_0 + \Delta t$; $\sim 100 \text{ ns} < \Delta t < \text{few } \mu\text{s}$
Laser Lifetime	3 year mission at 10% duty cycle $\sim 64 \text{ Mshots @ } 20 \text{ Hz}$	



L2MS Laser Overview



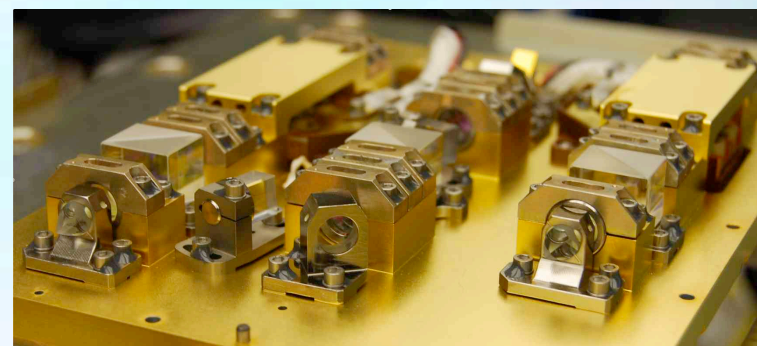
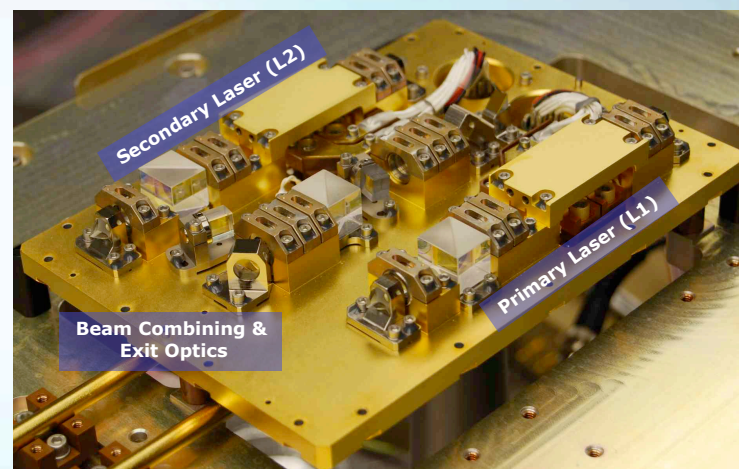
- Laser design for both Laser 1 (MIR) and Laser 2 (UV) is based on the previously flown Lunar Orbiter Laser Altimeter (LOLA) laser transmitter

LOLA laser transmitter

<i>Instrument</i>	LOLA
<i>Mission</i>	LRO
<i>Launched</i>	6/18/2009
<i>Laser type</i>	Cr:Nd:YAG, 5 way beam split
<i>Laser Architecture</i>	Cross-Porro resonator passively Q-switched
<i># of lasers</i>	2
<i>Laser Wavelength</i>	1064.3 ± 0.1 nm
<i>Laser pulse energy</i>	2.7 ± 0.3 mJ
<i>Laser Pulse Repetition Rate</i>	28.0 ± 0.1 Hz
<i>Laser Pulsewidth</i>	6.0 ± 2.0 ns
<i>Laser Beam quality</i>	TEM00
<i>Laser Divergence</i>	100 μ rad (= 5 m footprint)

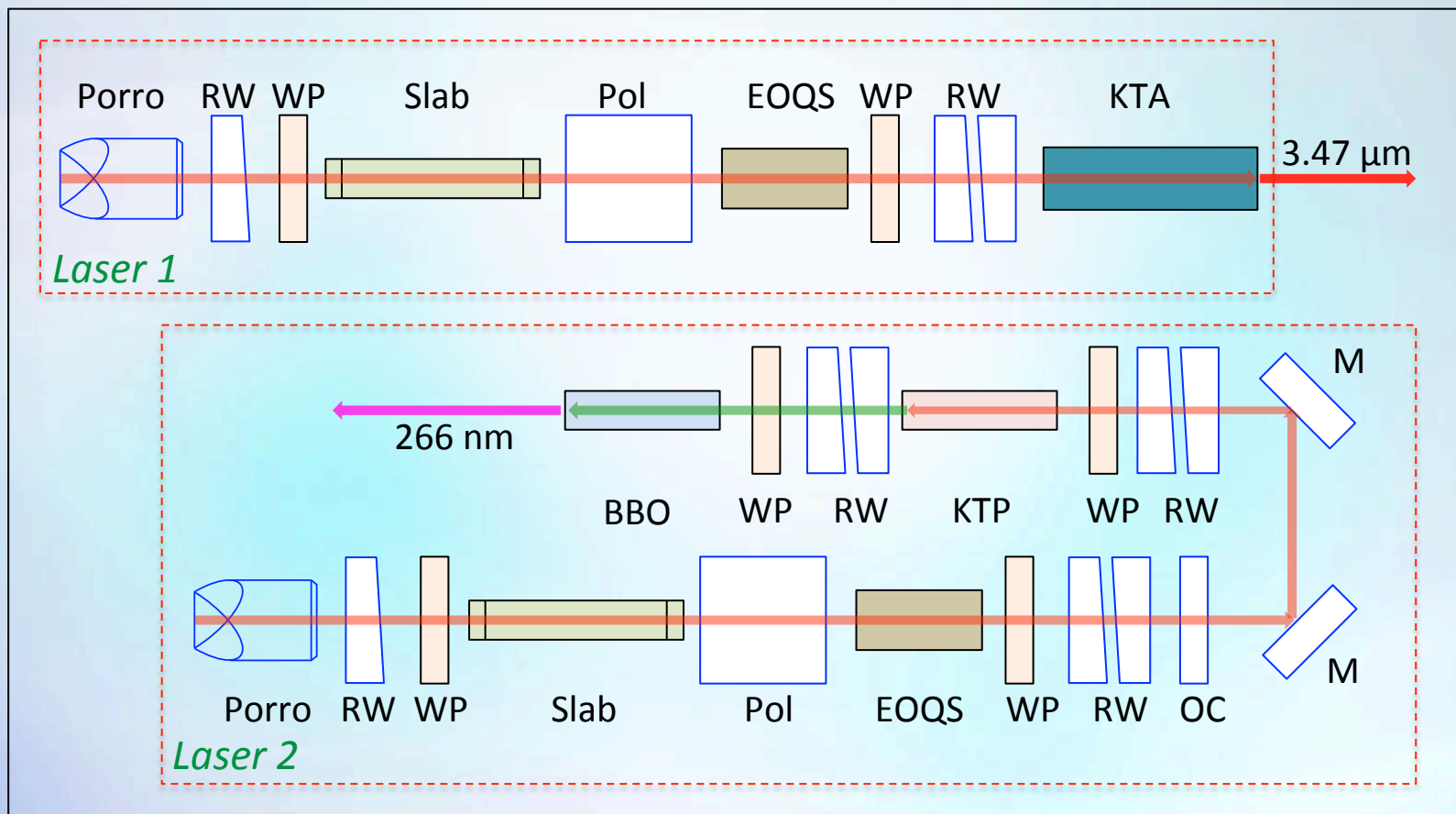
As of 3/2016, the number of shots fired by each lasers are:

- Laser 1 ~ 2.1B
- Laser 2 ~ 2B





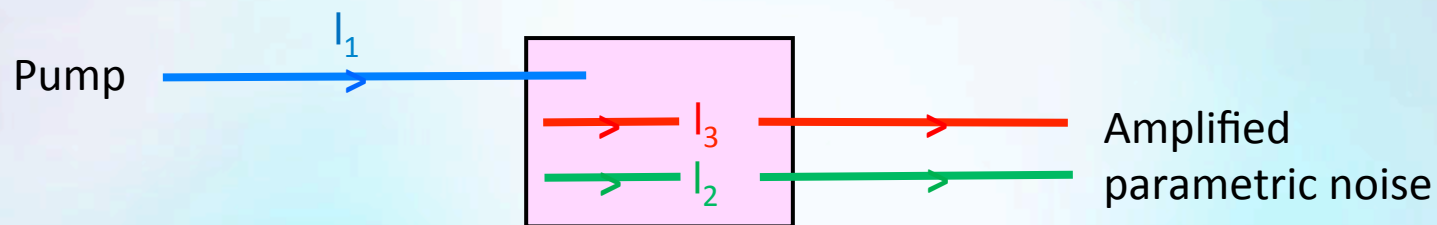
L2MS Laser Architecture



PP – Porro Prism; RW – Risley Wedge; WP – Wave plate; Pol – Polarizer; EOQS – Pockels Cell; M – Mirror; OC – Output Coupler



Parametric generation

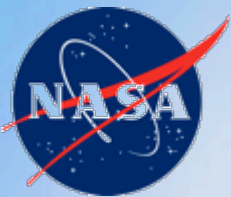


Input pump, hc/I_1 , spontaneously generates pairs of photons, hc/I_2 , hc/I_3 (parametric noise) which are then amplified.

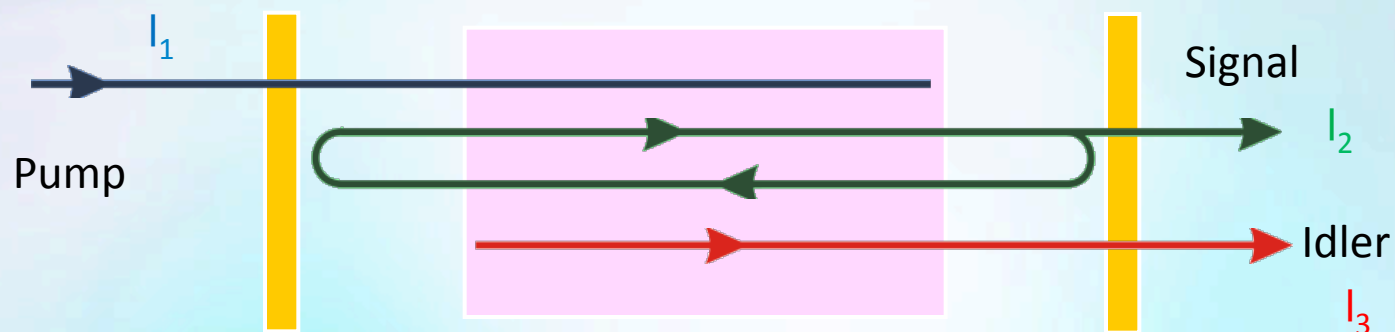
Energy conservation: $E = hc / I_1 = hc / I_2 + hc / I_3$

$$1 / 1064 \text{ nm} = 1 / 1651 \text{ nm} + 1 / 2993 \text{ nm}$$

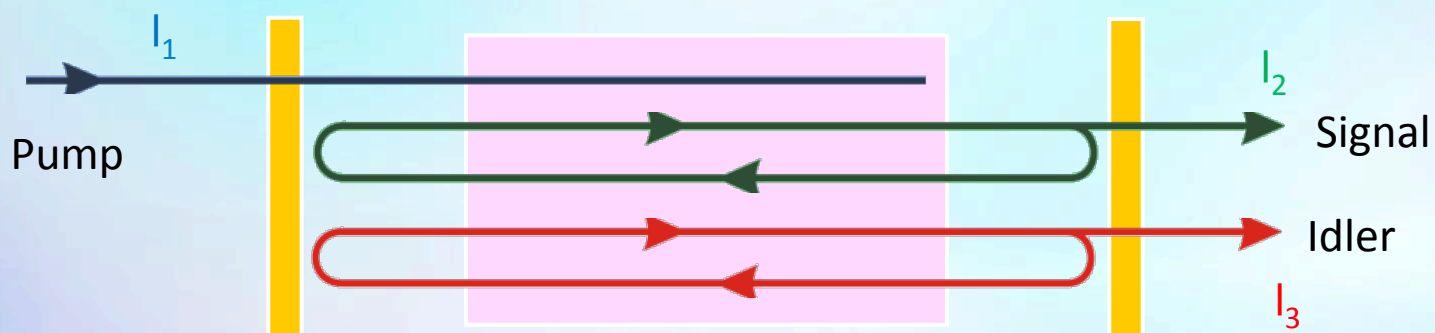
$$1 / 1064 \text{ nm} = 1 / 1573 \text{ nm} + 1 / 3288 \text{ nm}$$



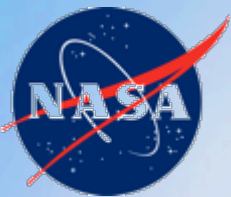
Optical parametric oscillation



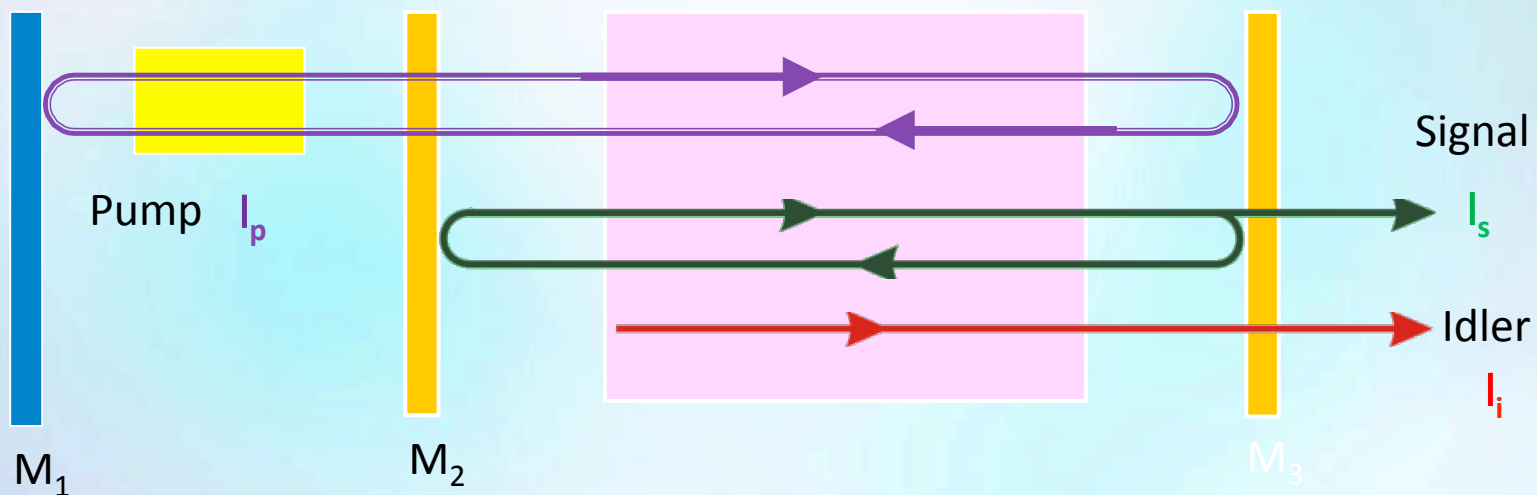
Singly-resonant oscillator (SRO)

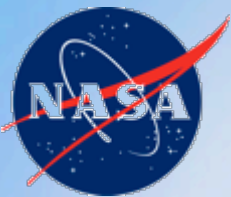


Doubly-resonant oscillator (DRO)



Intra-cavity OPO (iOPO)

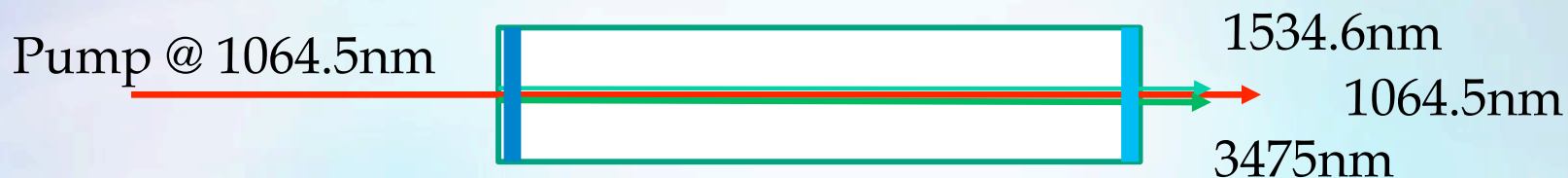




Monolithic OPO crystal design



Noncritical phase matching (NCPM)



Critical phase matching

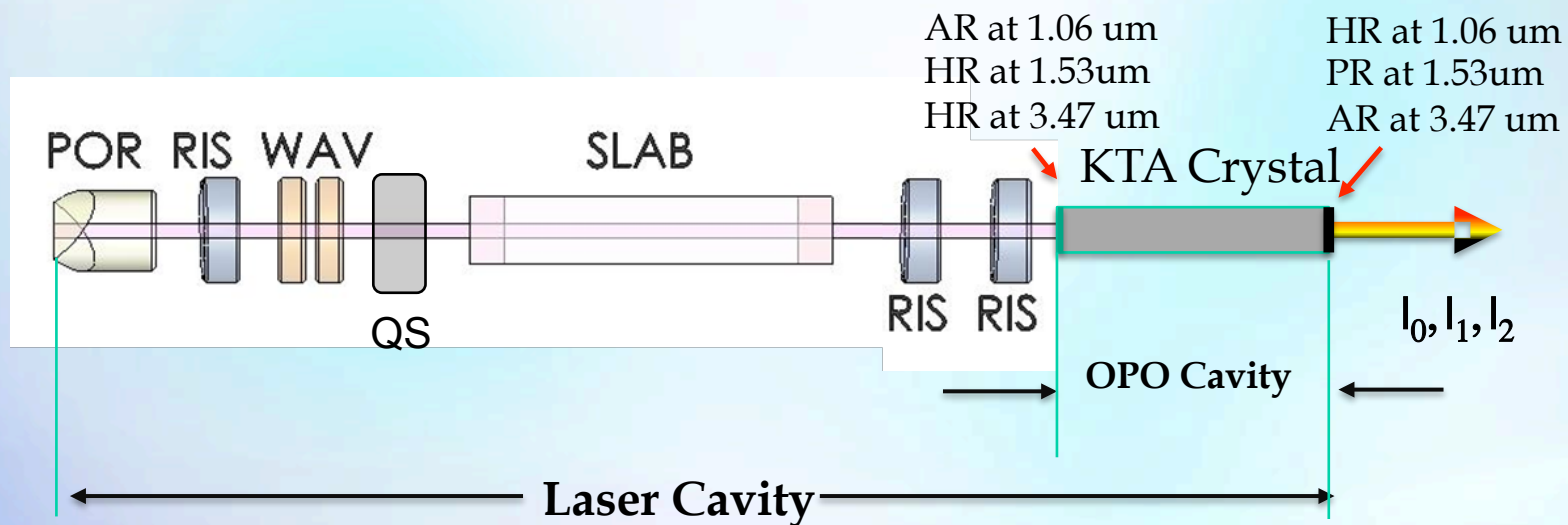




Monolithic iOPO Design

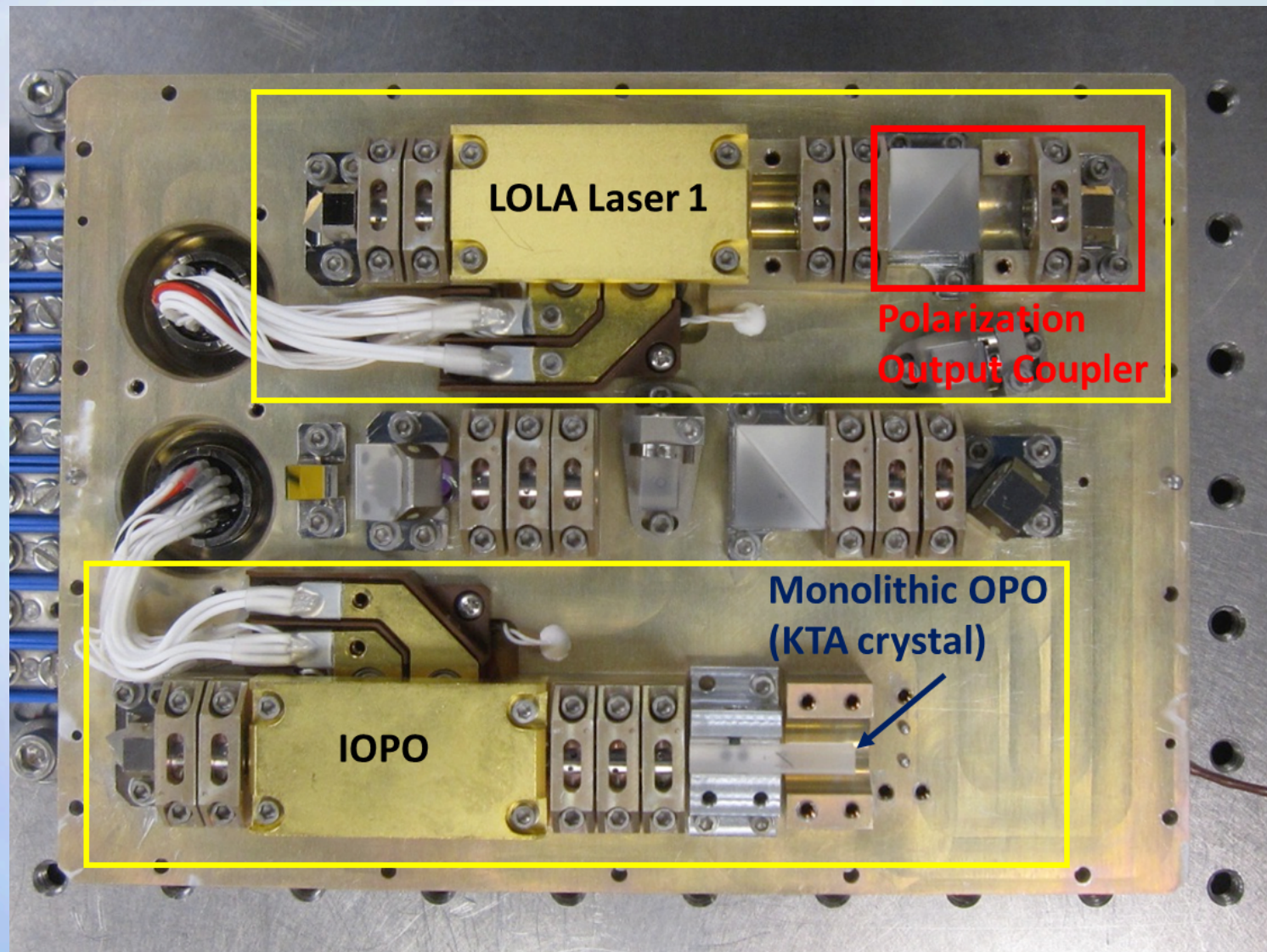


- Replace LOLA laser output coupling section with a monolithic OPO





Reconfigure LOLA to iOPO

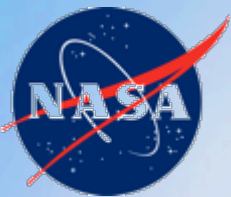




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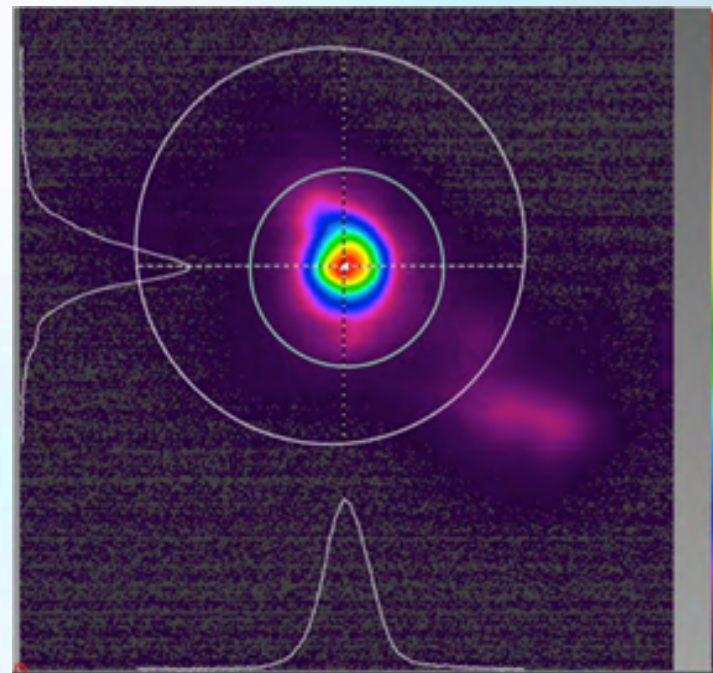
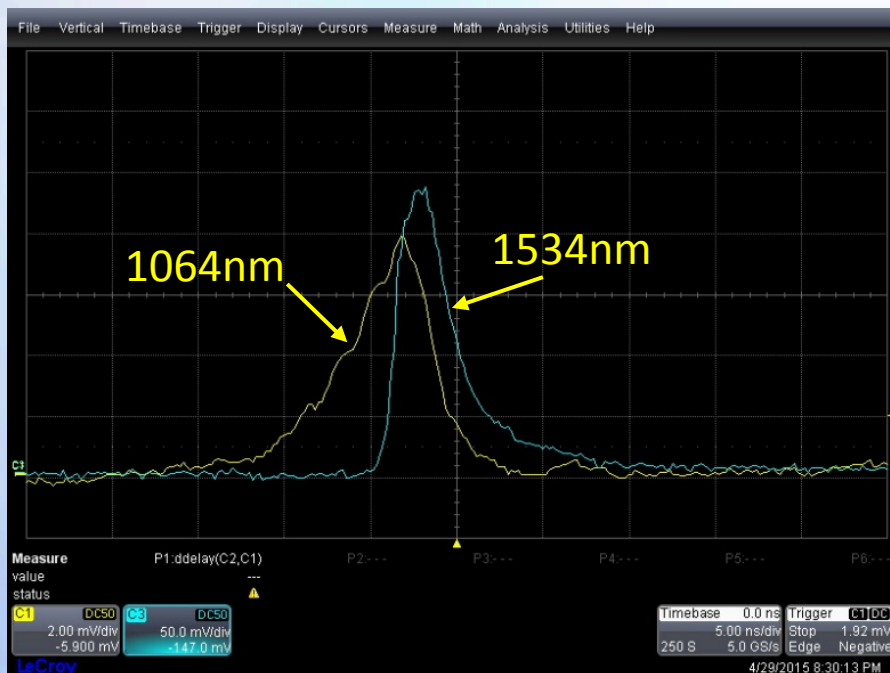
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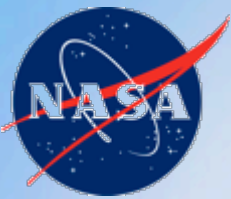


iOPO Experimental results, 3.4 μm



Output Energy = 450 μJ at 3471nm
= 1.2 mJ at 1534nm

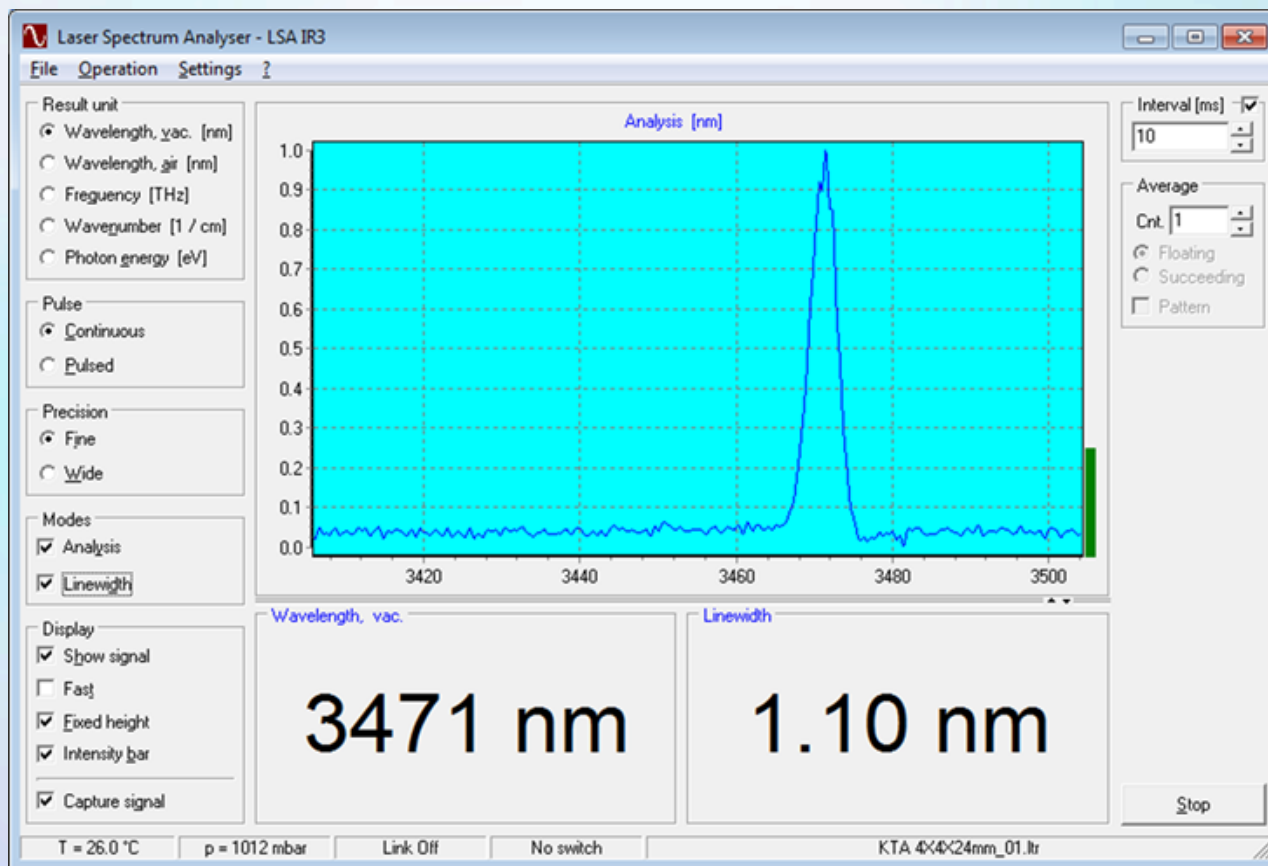




iOPO Experimental result, 3.4 μm

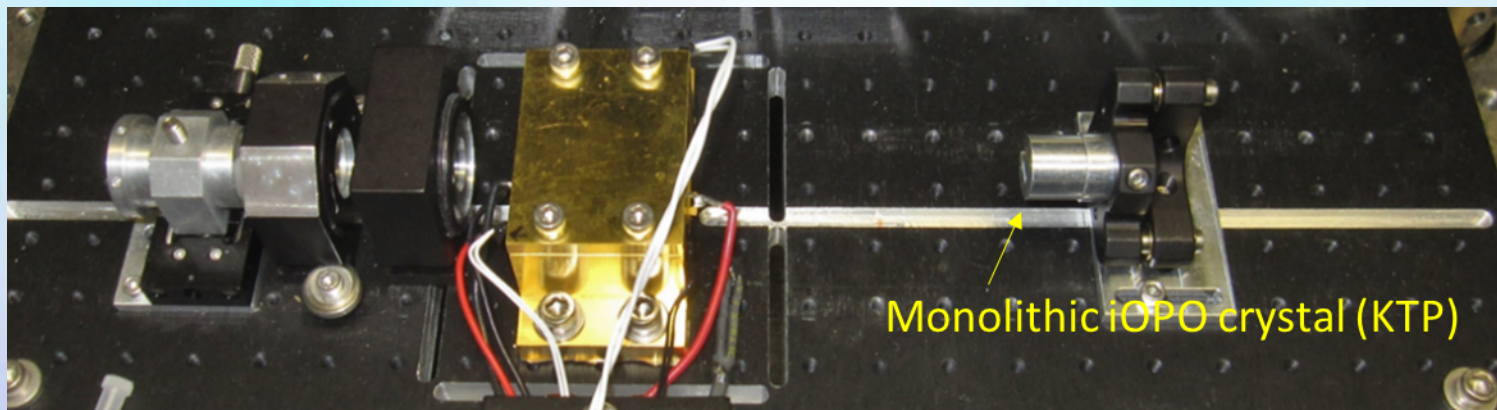
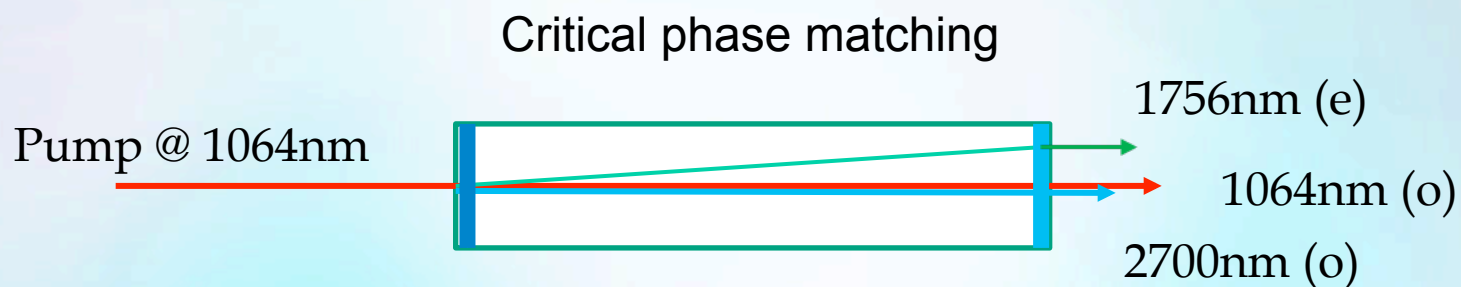


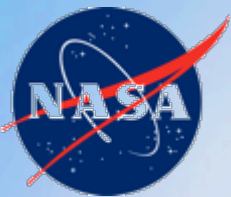
Goddard Space
Flight Center



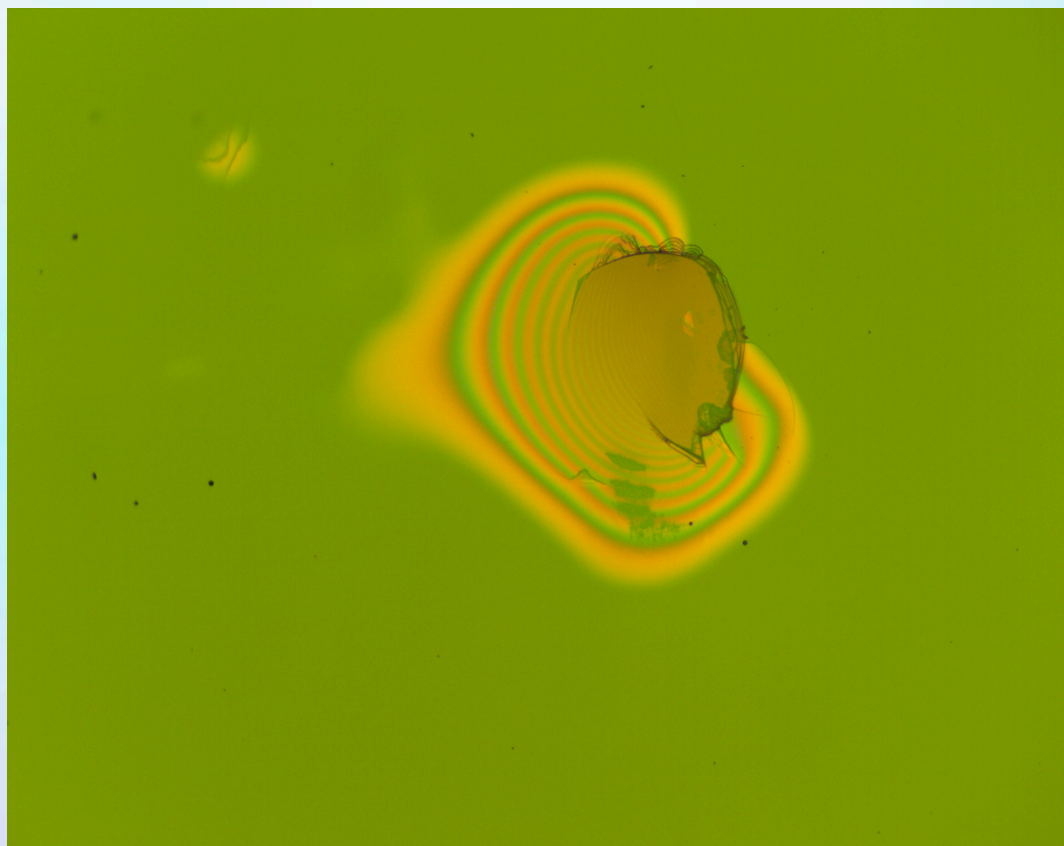


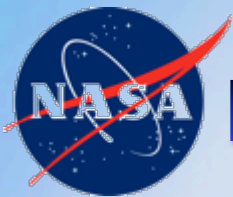
iOPO breadboard using CPM monolithic OPO crystal, 2.7 & 2.9 μm



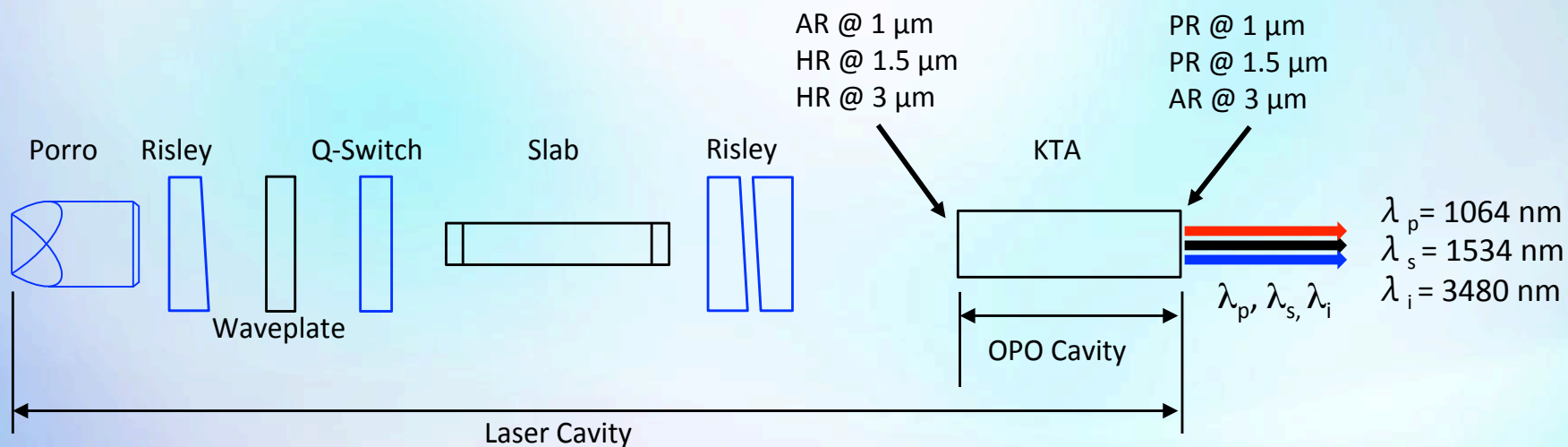
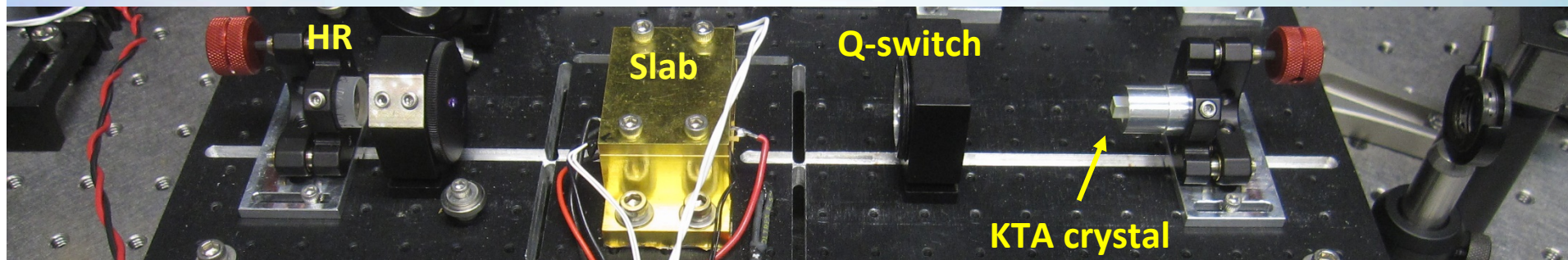


Coating damage near 2.85um





MIR Laser Breadboard

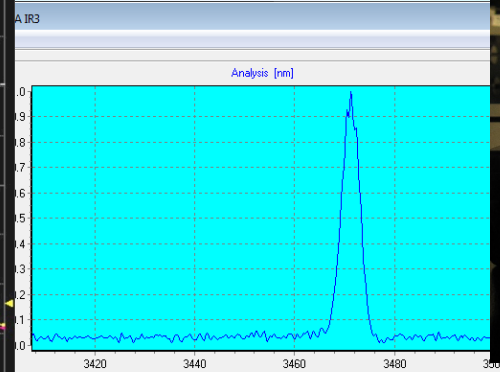
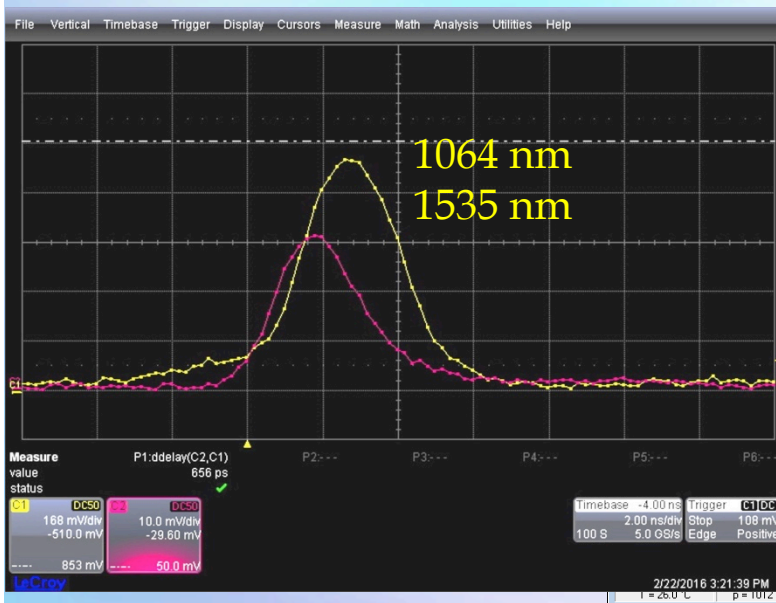




MIR Laser Breadboard Performance

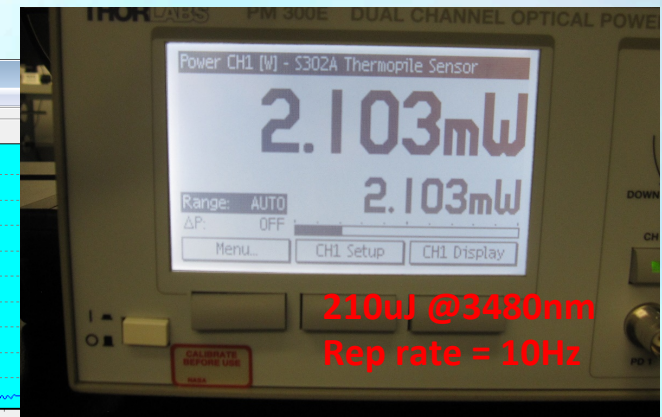


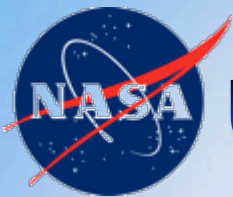
Parameter	Measurement	Requirement
Wavelength	3471 nm	3400 nm \pm 50 nm
Pulse Repetition Frequency (PRF)	20 Hz	1-20 Hz
Average Power	4.2 mW	NA
Energy	210 μ J	100 μ J
Pulse Duration	1.9 ns	< 7 ns
Conversion Efficiency	10.5 %	NA



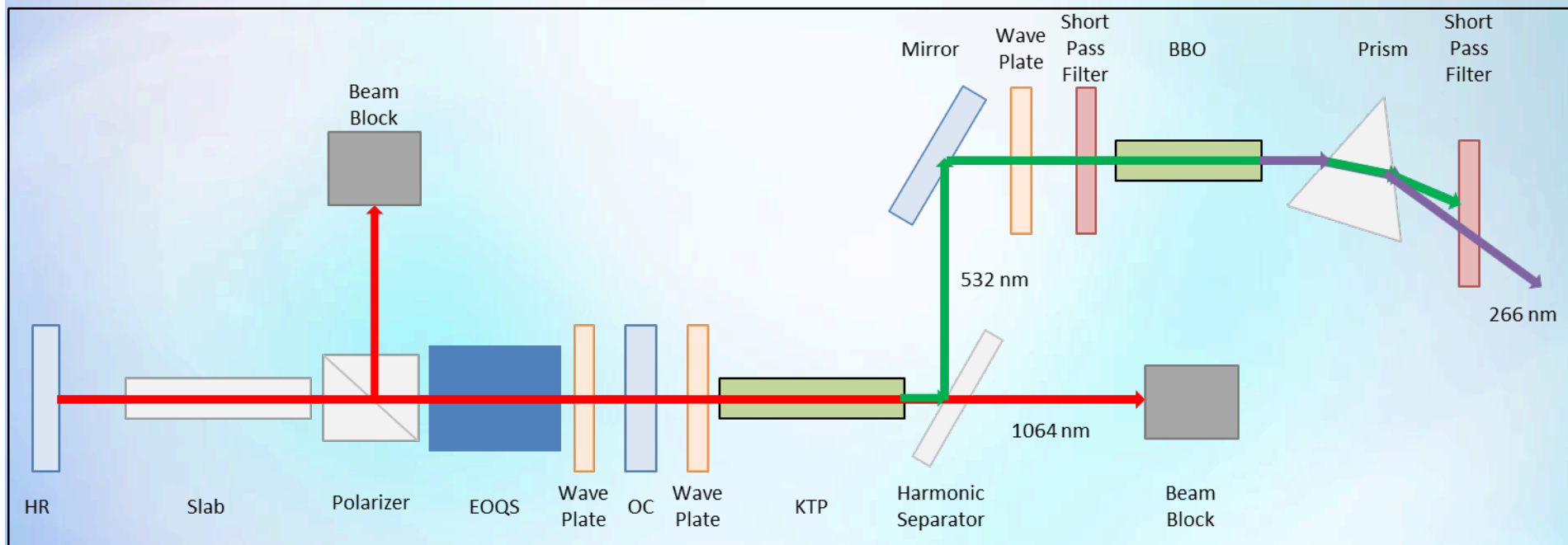
3471 nm

1.35 nm





UV Laser Breadboard

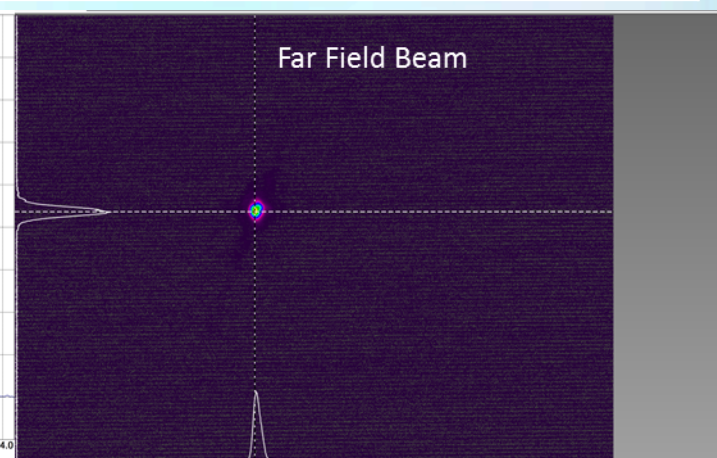
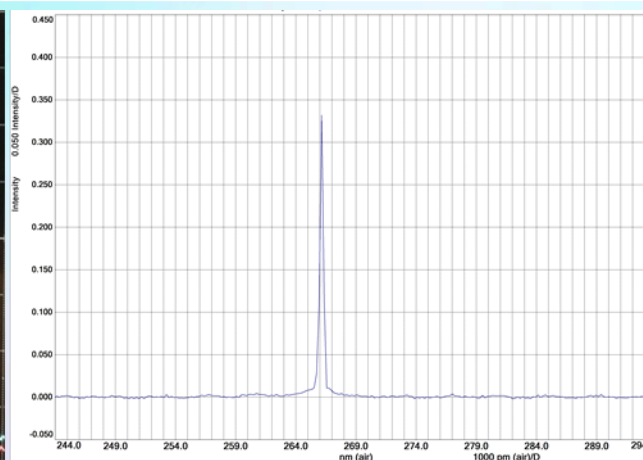
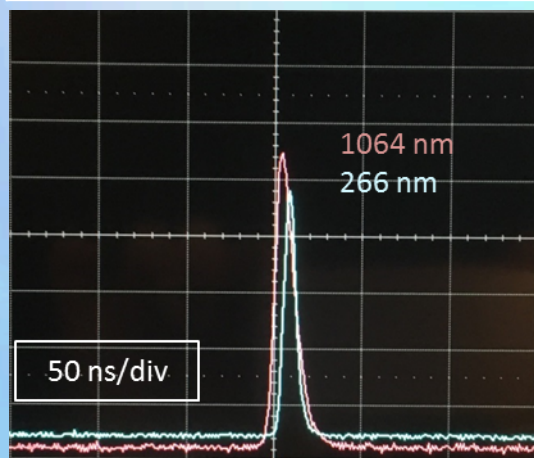




266 nm Laser Performance

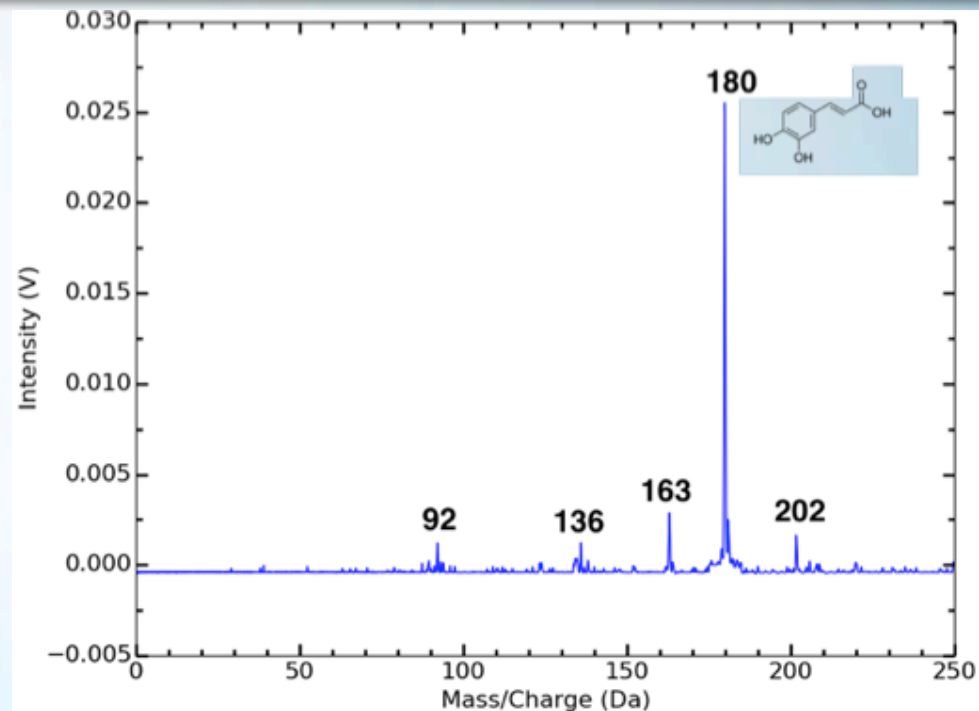
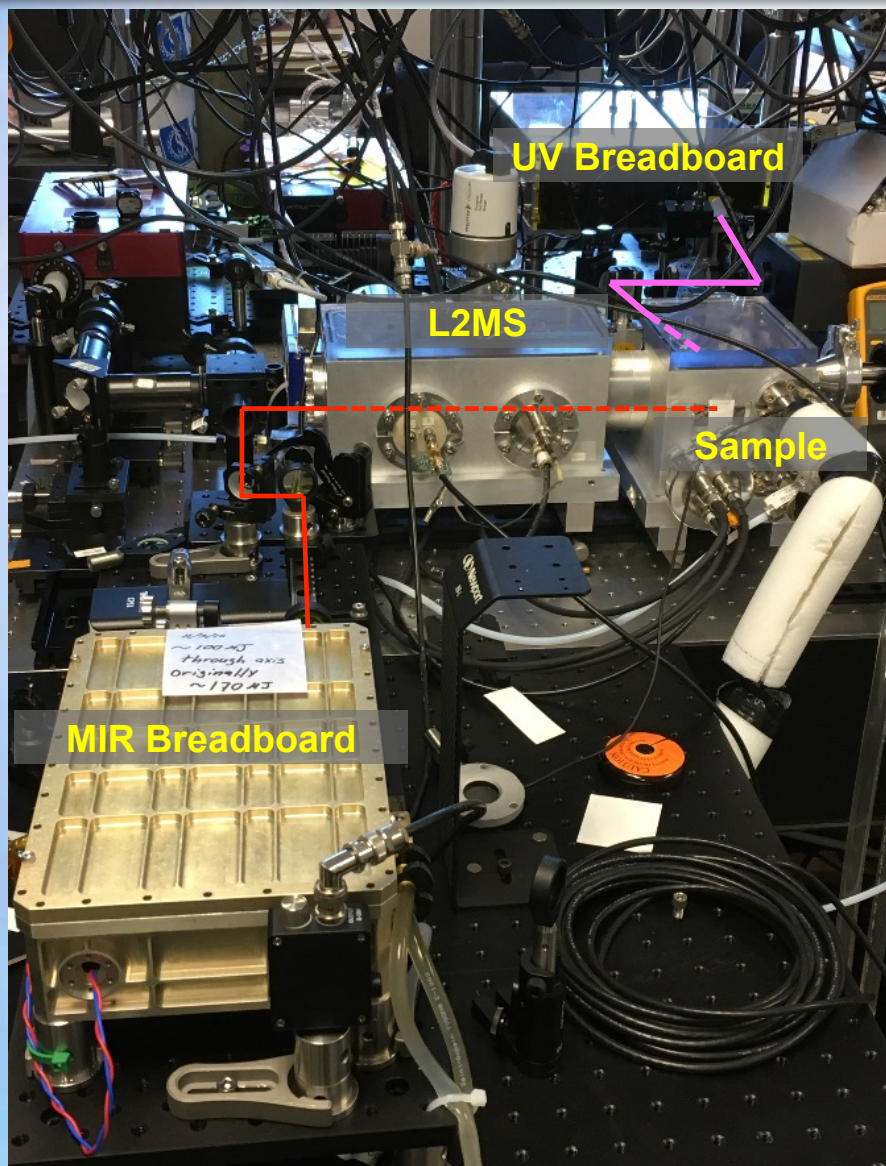


Parameter	Measurement	Requirement
Wavelength	266.2 nm	266 nm
Pulse Repetition Frequency (PRF)	20 Hz	1-20 Hz
Energy	220 μ J	18 μ J
Pulse Duration	6.6 ns	< 7 ns
Peak Power	32.5 kW	2.5 kW
Peak Intensity (assuming 100 μ m beam diameter)	415 MW/cm ²	30 MW/cm ²
Divergence (full angle)	$\theta_x = 0.66$ mrad $\theta_y = 1.12$ mrad	NA
Overall 4 th Harmonic Conversion Efficiency (1064 nm – 266 nm)	10%	NA





Integration of Laser to L2MS Instrument



- Successful coupling of the laser breadboards to the L2MS instrument enabled detection of caffeic acid encapsulated by a thin layer of water ice, for the first time
- A mass spectrum of caffeic acid coated with water ice, measured at cryogenic temperatures is shown above



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Future Work



Laser 1 – MIR Laser

- Test 3.4 μm breadboard with L2MS laboratory instrument and compare with commercial OPO
- Complete 2.75 μm breadboard laser
- Finalize design for dual wavelength (2.75 μm and 3.4 μm) concept

Laser 2 – UV Laser

- Investigate other non-linear optical crystals for SHG and FHG – leverage ICESat-2/ATLAS LBO aging study
- Optimize overall 4th harmonic conversion efficiency
- Test breadboard with L2MS laboratory instrument and compare with commercial UV laser
- Develop epoxy-free opto-mechanical design for mounting optics to minimize UV induced contamination on optical surfaces

Laser Transmitter

- Improve packaging of the laser transmitter for space flight
- Build brass board laser transmitter that will generate both MIR and UV wavelengths on a single laser bench



Conclusions



- We are developing a multi-wavelength laser transmitter for the L2MS Instrument
- A new laser architecture based on the LOLA laser transmitter that generates a single discrete MIR and UV wavelengths has been demonstrated
- The approach provides a straightforward path toward space laser design and deployment
- Preliminary laser breadboard results show compliance with the L2MS instrument requirements